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(54) Title: PROCESS FOR THE PREPARATION OF 1,1,1,2,2-PENTAFLUOROETHANE

(57) Abstract: A process for the preparation of pentafluoroethane is disclosed which involves contacting a mixture comprising hydrogen fluoride and at least one one starting material selected from haloethanes of the formula $CX_3191CHX_2$ and haloethenes of the formula $CX_2=CX_2$, where each X is independently selected from the group consisting of F and Cl (provided that no more than four of X are F), with a fluorination catalyst in a reaction zone to produce a product mixture comprising HF, HCl, pentafluoroethane, underfluorinated halogenated hydrocarbon intermediates and less than 0.2 mole percent chloropentafluoroethane based on the total moles of halogenated hydrocarbons in the product mixture. The process is characterized by the fluorination catalyst comprising (i) a crystalline cobalt-substituted alpha-chromium oxide where from about 0.05 atom % to about 6 atom % of the chromium atoms in the alpha-chromium oxide lattice are replaced by trivalent cobalt (Co^{+3}) and/or (ii) a fluorinated crystalline oxide of (i).

PROCESS FOR THE PREPARATION OF
1,1,1,2,2-PENTAFLUOROETHANE
FIELD OF THE INVENTION

5   The present invention relates to the synthesis of 1,1,1,2,2-pentafluoroethane.

BACKGROUND

The compound pentafluoroethane (CF_3CHF_2 or HFC-125) is useful as a blowing agent, propellant, refregerant, fire extinguishing agent, or

10   sterilant carrier gas. It is desirable for its zero ozone depletion potential.

Various methods for the preparation of pentafluoroethane have been disclosed. U.S. Patent No. 3,755,477 describes a process for producing fluorinated hydrocarbons using a chromia catalyst prepared by treating a chromium hydroxide paste with water or steam before it is dried

15   and calcined. Example 23 illustrates the conversion of tetrachloroethylene to a product mixture containing CF_3CHCl_2 (20%), CF_3CHClF (20%), CF_3CHF_2 (30%), and CF_3CClF_2 (20%); and Example 25 illustrates the conversion of CF_3CHCl_2 to a product mixture containing CF_3CHClF (21%), CF_3CHF_2 (67%) and CF_3CClF_2 (2.5%). Chloropentafluoroethane

20   (CF_3CClF_2 or CFC-115) is objectionable because it represents a yield loss and it is difficult to separate from pentafluoroethane by distillation.

U. S. Patent No. 3,258,500 describes a process for the catalytic vapor-phase fluorination of certain halohydrocarbons employing a catalyst that consists essentially of an activated anhydrous chromium (III) oxide.

25   Example 17 illustrates the conversion of tetrachloroethylene to a product mixture containing inter alia CF_3CHCl_2 (3.5%), CF_3CHClF (9.2%), and CF_3CHF_2 (35.0%) at 400°C and to a product mixture containing inter alia CF_3CHCl_2 (16.0%), CF_3CHClF (38.3%), and CF_3CHF_2 (25.4%) at 300°C; and Example 20 illustrates the conversion of chlorotrifluoroethylene to a

30   product mixture containing inter alia CF_3CHF_2 (26.8%) at 400°C.

Canadian Patent 849,024 and Canadian Patent 1,196,345 also disclose processes employing chromium-containing catalysts that may be used to produce pentafluroethane.

U. S. Patent No. 4,843,181 discloses a gas phase process for the

35   manufacture of CF_3CHCl_2 and/or CF_3CHClF by contacting a suitable tetrahaloethylene and/or pentahaloethane with HF in the presence of Cr_2O_3 prepared by the pyrolysis of $(NH_4)_2Cr_2O_7$, the reaction being

conducted under controlled conditions whereby the production of CF_3CClF_2 is minimized.

There is a need for other useful methods of preparing CF_3CHF_2 where the amount of chloropentafluoroethane by-product is low.

<u>SUMMARY OF THE INVENTION</u>

This invention provides a process for the preparation of pentafluoroethane. The process comprises contacting a mixture comprising hydrogen fluoride (HF) and at least one one starting material selected from haloethanes of the formula CX_3CHX_2 and haloethenes of the formula $CX_2=CX_2$, where each X is independently selected from the group consisting of F and Cl provided that no more than four of X are F, with a fluorination catalyst in a reaction zone to produce a product mixture comprising HF, HCl, pentafluoroethane, underfluorinated halogenated hydrocarbon intermediates and less than 0.2 mole percent chloropentafluoroethane based on the total moles of halogenated hydrocarbons in the product mixture. The process is characterized by said fluorination catalyst comprising at least one chromium-containing component selected from (i) a crystalline cobalt-substituted alpha-chromium oxide where from about 0.05 atom % to about 6 atom % of the chromium atoms in the alpha-chromium oxide lattice are replaced by trivalent cobalt (Co^{+3}), and (ii) a fluorinated crystalline oxide of (i).

<u>DETAILED DESCRIPTION</u>

In the fluorination step of the process of this invention, one or more haloethane compound(s) of the formula CX_3CHX_2, or one or more haloethene compound(s) of the formula $CX_2=CX_2$, or a mixture thereof, where each X is independently selected from the group consisting of F and Cl (provided that no more than four of X are F) are typically reacted with substantially anhydrous hydrogen fluoride (HF). Suitable halogenated starting materials for the process of this invention include $CCl_2=CCl_2$, $CClF=CCl_2$, $CClF=CClF$, $CF_2=CCl_2$, $CClF=CF_2$, $CF_2=CF_2$, $CHCl_2CCl_3$, $CHCl_2CCl_2F$, $CHClFCCl_3$, $CHCl_2CClF_2$, $CHClFCCl_2F$, CHF_2CCl_3, $CHClFCClF_2$, $CHCl_2CF_3$, CHF_2CClF_2, and $CHClFCF_3$. Preferred starting materials are $CCl_2=CCl_2$, $CHCl_2CF_3$, and $CHClFCF_3$. Tetrachloroethene is an available item of commerce. 2,2-Dichloro-1,1,1-trifluoroethane may be prepared by the reaction of tetrachloroethene with HF in the presence of tantalum pentafluoride as disclosed by Gumprecht and Schindel in U. S. Patent No. 4,967,024. 2-Chloro-1,1,1,2-tetrafluoroethane may be prepared by chlorination of 1,1,1,2-

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tetrafluoroethane as disclosed by Manzer et. al. in U. S. Patent
No. 5,302,765.

Preferably, the reaction of HF and with haloethanes and
haloethenes is carried out in the vapor phase in a heated tubular reactor.
5   A number of reactor configurations are possible including horizontal or
vertical orientation of the reactor and different modes of contacting the
halogenated starting materials with HF.

In one embodiment of the invention, the organic starting material(s)
may be initially vaporized and fed to the reactor as gas(es).

10 In another embodiment of the invention, the organic starting
material(s) may be contacted with HF in a pre-reactor. The pre-reactor
may be empty, but is preferably filled with a suitable packing such as
Monel™ or Hastelloy™ nickel alloy turnings or wool, or other material inert
to HCl and HF which allows for efficient mixing of haloethane or

15 haloethene and HF vapor.

Suitable temperatures for the pre-reactor are within the range of
from about 80°C to about 250°C, preferably from about 100°C to about
200°C. For haloethane and haloethene starting materials having fewer
than three fluorine substituents, some substitution of chlorine substituents

20 by fluorine may occur in the pre-reactor. Higher temperatures result in
greater conversion of the CX_3CHX_2 and $CX_2=CX_2$ entering the reactor
and a greater degree of fluorination in the converted products. Under
these conditions, for example, tetrachloroethene may be converted to a
mixture containing predominantly $CHCl_2CCl_2F$ and $CHCl_2CClF_2$.

25 The term "degree of fluorination" reflects the number of fluorine
substituents that replace chlorine substituents in the CX_3CHX_2 and
$CX_2=CX_2$ starting materials. For example, CF_3CHF_2 represents a higher
degree of fluorination than CF_3CHCl_2 and $CF_2=CCl_2$ represents a higher
degree of fluorination than $CCl_2=CCl_2$. The term "underfluorinated

30 halogenated hydrocarbon intermediates" means haloethanes of the
formula CX_3CHX_2 wherein at least one X is Cl, and haloethenes of the
formula $CX_2=CX_2$. Examples of underfluorinated intermediates are
$CCl_2=CCl_2$, $CClF=CCl_2$, $CClF=CClF$, $CF_2=CCl_2$, $CClF=CF_2$, $CF_2=CF_2$,
$CHCl_2CCl_3$, $CHCl_2CCl_2F$, $CHClFCCl_3$, $CHCl_2CClF_2$, $CHClFCCl_2F$,

35 CHF_2CCl_3, $CHClFCClF_2$, $CHCl_2CF_3$, CHF_2CClF_2, and $CHClFCF_3$ (i.e.,
the same compounds suitable as starting materials). Underfluorinated
halgenated hydrocarbon intermediates may include unreacted starting

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material, but do not include either pentafluoroethane (i.e., the desired product) or chloropentfluoroethane (i.e., an undesireable by-product).

The molar ratio of HF to CX_3CHX_2 and $CX_2=CX_2$ starting material(s) in the pre-reactor is typically from about the stoichiometric ratio of HF to CX_3CHX_2 and $CX_2=CX_2$ to about 40:1. The stoichiometric ratio of HF to the starting material depends on the whether the starting materials is a haloethane or a haloethene, or a mixture, and the average degree of fluorination of the starting material(s) fed to the pre-reactor. For example, if the starting material is $CCl_2=CCl_2$, the stoichiometric ratio of HF to $CCl_2=CCl_2$, is 5:1 for formation of CF_3CHF_2; if the starting material is CF_3CHCl_2, the stoichiometric ratio of HF to CF_3CHCl_2 is 2:1. Preferably, the molar ratio of HF to starting material in the pre-reactor is from about twice the stoichiometric ratio of HF to haloethane or haloethene to about 15:1. Higher molar ratios of HF to starting material are not particularly beneficial. Lower ratios result in reduced yields of HFC-125 unless additional HF is co-fed to the reaction zone.

In a preferred embodiment of the invention, in step (a) the CX_3CHX_2 and $CX_2=CX_2$ starting material(s) are vaporized, preferably in the presence of HF, and then fed to the reactor zone. If he preferred amounts of HF are fed in the pre-reactor, additional HF is not required in the reaction zone.

The contacting of the organic starting materials with HF in the presence of the catalyst, preferably pretreated, of the instant invention in the reaction zone is performed at an effective temperature, mole ratio and contact time. By effective temperature, mole ratio and contact time is meant the temperatures, mole ratios and contact times which produce a product stream which contains CF_3CHF_2 in a major proportion, preferably in an amount of at least 50 mole %, more preferably at least about 60 mole %, as determined by gas chromatography.

With CF_3CHCl_2 or CF_3CHClF as the reactant, the temperature will normally range from about 300°C to about 380°C, preferably about 330°C to 350°C. The HF/organic mole ratio will normally range from about 1.5/1 to about 10/1, preferably from about 2/1 to 8/1. The contact time will vary widely but preferably will be such as to provide an average residence time of from 2 to 100 seconds, and more preferably 10 to 50 seconds.

The pressure is not critical but should be sufficient to maintain HF, the organic reactant and the reactant product stream components in the vapor state at the operating temperature. Reactor pressures of about

5 atmospheres to about 30 atmospheres may be advantageously employed to facilitate separation of HCl from other reaction products in step (b) of the process.

In general, the higher the temperature, the greater the HF/organic
5   mole ratio, and the longer the contact time, the greater is the conversion of the reactants to fluorinated products, and the greater is the degree of fluorination of the raw material. The above variables can be balanced, one against the other, so that formation of CF_3CHF_2 is maximized and that of perhalogenated by-products is minimized, preferably to less than
10 about 3%, with that of $CClF_2CF_3$ to less than 2%, more preferably to less than 1%, and most preferably less than 0.2%, said percents being mole percents as determined by gas chromatography.

This process allows unreacted starting material and other underfluorinated intermediates to be recycled to the reactor for the
15 production of additional CF_3CHF_2. For example, the fluorination step (step (a)) may be advantageously followed by a separation step (step(b)) separating the product of step (a) to recover CF_3CHF_2 as a product and to obtain underfluorinated halogenated hydrocarbon intermediates; and a recycle step (step (c)) returning underfluorinated halogenated hydrocarbon
20 intermediates obtained in step (b) back to the step (a) reaction zone.

In step (b) the effluent from the reaction zone in step (a) comprising CF_3CHF_2, HCl, HF, and the underfluorinated halogenated ethanes and ethenes, is delivered to one or more separation zones in which CF_3CHF_2 is separated from the HCl, excess HF, and underfluorinated halogenated
25 ethanes and ethenes. The separation zones may comprise conventional chemical processing equipment such as, but not limited to, scrubbers, decanters, and/or distillation columns. The pentafluoroethane is recovered.

In step (c) of the process of this invention, underfluorinated
30 halogenated ethanes and ethenes, as well as excess HF obtained in the separation zone(s) may be returned to step (a). Limited amounts of pentafluoroethane and chloropentafluoroethane may also be returned to the reaction zone as long as the product mixture contains less than 0.2 mole percent chloropentafluoroethane based on the total moles of
35 halogenated hydrocarbons therein.

Of note are embodiments where $CCl_2=CCl_2$ is used as the starting material and a recycle comprising $CHCl_2CF_3$, $CHClFCF_3$ or both $CHCl_2CF_3$ and $CHClFCF_3$ is returned to the reaction zone in step (c).

The reaction zone in the fluorination step (e.g., step (a)) of the process of the invention may contain a fluorination catalyst comprising a crystalline cobalt-substituted alpha chromium oxide where from about 0.05% to about 6% of the chromium in the alpha-chromium oxide lattice is

5   replaced by trivalent cobalt (Co^{+3}) based on the total of the cobalt and chromium in the alpha-chromium oxide. These cobalt-substituted alpha-chromium oxides have the general formula α-$Co_xCr_{2-x}O_3$ where x = 0.001-0.12. Crystalline oxides of this formula may be fluorinated before use in the reaction zone. Further information on cobalt-substituted alpha-

10 chromium oxides useful for this invention is provided in U.S. Patent Application 60/405,220 [CL2099 US PRV] filed August 22, 2002, and hereby incorporated by reference herein in its entirety.

These cobalt/chromium oxide compositions may be prepared by co-precipitation from aqueous solutions of cobalt(II) and chromium(III)

15 salts. Preferably, the cobalt and chromium salts are co-precipitated by adding ammonium hydroxide (aqueous ammonia) to an aqueous solution of a soluble divalent cobalt salt and a soluble trivalent chromium salt wherein the concentration of divalent cobalt is from about 0.05 mole % to about 6 mole % of the total of cobalt and chromium in the solution, said

20 solution containing at least three moles of nitrate (i.e., NO_3^-) per total mole of chromium (i.e., Cr^{3+}) and at least three moles of ammonium (i.e., NH_4^+) per mole of chromium (i.e., Cr^{3+}) before the co-precipitated solid is collected. After precipitation is complete, water is evaporated from the mixture, and the resulting solid is dried and calcined as discussed in the

25 co-pending patent application referenced above.

Of note are preparations where excess ammonium nitrate (i.e., more than three moles of ammonium nitrate per mole of chromium) is present in the aqueous solution. For example, in addition to the ammonium nitrate already present from reaction of ammonium hydroxide

30 with chromium nitrate, from about 0.1 mole to about 7.0 moles of additional ammonium nitrate per mole of chromium may be added to the solution before, during, or after the co-precipitation of the compositions. Surprisingly, we have found that addition of excess ammonium nitrate to the precipitated mixture of cobalt and chromium hydroxides prior to the

35 dehydration step may be used to decrease the particle size of the α-$Co_xCr_{2-x}O_3$ phase which in turn increases the surface area of that phase and the activity of the catalyst (see PREPARATION EXAMPLES 5 and 6). The ammonium nitrate treatment also tends to increase the selectivity of

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the final cobalt/chromium oxide catalyst (see EXAMPLES 2, 3, 6, 9, 15, 16, 17, and 18).

After the ammonium nitrate is added to the mixture, it is preferably stirred for about 0.5 to ten hours (more preferably one to five hours) at a
5   temperature of from about 20°C to about 60°C. The mixture is then dried and calcined.

Other agents that serve this purpose include aqueous hydrogen peroxide (1% to 30% solutions), ozone, peroxy acids such as peroxyacetic acid, and ammonium persulfate. Agents such as halogens may be used,
10   but are not preferred. Agents containing alkali metals such as potassium persulfate or sodium perborate may also be used but are not preferred.

After the precipitation of the mixture of cobalt and chromium hydroxides is complete, and excess ammonium nitrate or other agents added if desired, the mixture is dried by evaporation.

15   Optionally, the precipitated mixture of cobalt and chromium hydroxide may be collected and, if desired, washed with deionized water before drying. This may influence the activity of the catalyst.

After the cobalt and chromium hydroxide mixture has been dried, the nitrate salts are then decomposed by heating the solid from about
20   250°C to about 350°C. The resulting solid is then calcined at temperature of from about 375°C to about 1000°C, preferably from about 400°C to about 600°C. Lower calcination temperatures may result in the presence of some residual nitrate impurities in the metal oxide. The calcination temperature can influence the activity of the catalysts. The calcination is
25   preferably carried out in the presence of oxygen, most preferably in the presence of air.

After calcination, the resulting metal-substituted crystallites are not visually distinguishable from α-Cr_2O_3 by transmission electron microscopy. Furthermore, X-ray and electron diffraction studies are
30   entirely consistent with the α-Cr_2O_3 structure with some lattice contraction proportional to the amount of Co(III) substituted for Cr(III) in the α-Cr_2O_3 structure. Further details on the characterization of these compositions are provided in the concurrently filed patent application referenced above and incorporated herein by reference.

35   The cobalt content of the chromium oxide compositions of the present invention effects the activity of the catalyst obtained after fluorinating the mixed metal oxide. For example, the data in Table 1 shows that substitution of Co^{+3} into the α-Cr_2O_3 lattice, particularly in the

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range of 1-2%, results in a catalyst with comparable or higher activity relative to chromium oxide which does not contain cobalt. In addition, partial substitution of Co^{+3} for Cr^{+3} in the α-Cr_2O_3 lattice results in a catalyst that produces low amounts of CFC-115. Higher cobalt loadings reduce the activity of the catalyst. Furthermore, in accord with the teachings of this invention the performance of a catalyst composition containing a given ratio of cobalt to chromium may be enhanced by treating the initial solution of cobalt(II) and chromium(III) nitrates with an agent such as ammonium nitrate prior to dehydration and calcination.

TABLE 1

Activity of Fluorinated Cobalt/Chromium Oxides for

Fluorination of $CHClFCF_3$ to CHF_2CF_3 [a]

Cr/Co Ratio	CF_3CClF_2 (ppm) in 70% 125 in exit	% CF_3CHF_2 in Product at 330°C
100/0	1000	66
99/1	420	67
98/2	210	70
98/2	550	62[b]
97/3	830	48
95/5	574	56
95/5	1000	55[b]
95/5 excess NH_4NO_3	447	58
90/10	-[c]	13
90/10 excess NH_4NO_3	-[c]	48

a. Catalysts were prepared by co-precipitation technique using ammonia.
b. Separate catalyst preparation.
c. Catalyst not active enough to generate 70% 125 in effluent. As suggested in U.S. Patent Application 60/405,220 [CL2099 US PRV] filed August 22, 2002, these catalysts may be expected to differ significantly from compositions containing lower proportions of Co due to the solubility limit of Co in alpha chromium oxide.

The catalyst compositions used in the process of this invention may further comprise one or more additives in the form of metal compounds that alter the selectivity or activity of the crystalline cobalt-substituted alpha chromium oxides or the fluorinated metal oxide catalysts containing

cobalt and chromium. Suitable additives may be selected from the group consisting of fluoride, oxide, or oxyfluoride compounds of Mg, Ca, Sc, Y, La, Ti, Zr, Hf, V, Nb, Ta, Mo, W, Mn, Re, Fe, Ru, Co, Rh, Ir, Ni, Pd, Pt, Cu, Ag, Au, Ce, and Zn.

5   The total content of metal compound additive(s) in the catalyst compositions used in the present invention may be up to about 15 atom % based on the total metal content of the compositions (e.g. from about 0.05 atom % to 5 atom %). The additives may be incorporated into the compositions of the present invention by standard procedures.

10   Generally, the calcined compositions will be pre-treated with a fluorinating agent prior to use as catalysts for changing the fluorine content of halogenated carbon compounds. Accordingly, the reaction zone in the fluorination step (e.g., step (a)) of the process of the invention may contain a fluorination catalyst comprising a fluorinated crystalline cobalt-15   substituted alpha chromium oxide (where from about 0.05% to about 6% of the chromium in the alpha-chromium oxide lattice is replaced by trivalent cobalt based on the total of the cobalt and chromium in the alpha-chromium oxide). Typically this fluorinating agent is HF though other materials may be used such sulfur tetrafluoride, carbonyl fluoride, and 20   fluorinated carbon compounds such as trichlorofluoromethane, dichlorodifluoromethane, chlorodifluoromethane, trifluoromethane, or 1,1,2-trichlorotrifluoroethane. This pretreatment can be accomplished, for example, by placing the catalyst in a suitable container which can be the reactor to be used to perform the process in the instant invention, and 25   thereafter, passing HF over the dried, calcined catalyst so as to partially saturate the catalyst with HF. This is conveniently carried out by passing HF over the catalyst for a period of time, for example, about 0.1 to about 10 hours at a temperature of, for example, about 200°C to about 450°C. Nevertheless, this pre-treatment is not essential.

30   The reaction zone and its associated feed lines, effluent lines, and associated units should be constructed of materials resistant to hydrogen fluoride and hydrogen chloride. Typical materials of construction, well-known to the fluorination art, include stainless steels, in particular of the austenitic type, the well-known high nickel alloys, such as Monel[TM] nickel-35   copper alloys, Hastelloy[TM] nickel-based alloys and, Inconel[TM] nickel-chromium alloys, and copper-clad steel.

The product of this invention, 1,1,1,2,2-pentafluoroethane (HFC-125), is useful as a refrigerant and fire extinguishant.

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Without further elaboration, it is believed that one skilled in the art can, using the description herein, utilize the present invention to its fullest extent. The following specific embodiments are, therefore, to be construed as merely illustrative, and do not constrain the remainder of the

5   disclosure in any way whatsoever.

EXAMPLES

Catalyst Preparations

COMPARATIVE PREPARATION EXAMPLE 1

Preparation of 100% Chromium Catalyst (400°C)

10   A solution of 400 g $Cr(NO_3)_3[9(H_2O)]$ (1.0 mole) in 1000 mL of deionized water was treated dropwise with 477 mL of 7.4M aqueous ammonia raising the pH to about 8.5. The slurry was stirred at room temperature overnight. After re-adjusting the pH to 8.5 with ammonia, the mixture was poured into evaporating dishes and dried in air at 120°C. The

15   resulting solid was then calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 2

Preparation of 99%Chromium/1%Cobalt Catalyst (400°C)

A solution of 792.29 g $Cr(NO_3)_3[9(H_2O)]$ (1.98 moles) and 5.82 g $Co(NO_3)_2[6(H_2O)]$ (0.0200 mole) was prepared in 2000 mL of deionized

20   water. The solution was treated dropwise with 955 mL of 7.4M aqueous ammonia which raised the pH to about 8.5. The slurry was stirred at room temperature overnight. The pH was adjusted to 8.5 the following day. The solid was then collected using two fritted funnels; the resulting solid in each funnel was washed with 15-20 liters of deionized water. The solids

25   were dried in air at 120°C for 24 hours and then calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 3

Preparation of 98%Chromium/2%Cobalt Catalyst (400°C)

A solution of 784.30 g $Cr(NO_3)_3[9(H_2O)]$ (1.96 moles) and 11.64 g

30   $Co(NO_3)_2[6(H_2O)]$ (0.040 mole) was prepared in 2000 mL of deionized water. The solution was treated dropwise with 950 mL of 7.4M aqueous ammonia which raised the pH from about 1.8 to about 8.5. The slurry was stirred at room temperature overnight and then evaporated to dryness in air at 110-120°C for 48 hours. The dried catalyst was divided in half. One

35   half was calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 4
Preparation of 95%Chromium/5%Cobalt Catalyst
(1.6 eq. of excess NH_4NO_3, 400°C)

A solution of 760.28 g $Cr(NO_3)_3[9(H_2O)]$ (1.90 moles) and 29.10 g
$Co(NO_3)_2[6(H_2O)]$ (0.10 mole) was prepared in 2000 mL of deionized
water. The solution was treated dropwise with 950 mL of 7.4M aqueous
ammonia; the pH reached 8.5. The slurry was stirred at room temperature
for 24 hours and then treated with a solution of 240.12 g NH_4NO_3 (3.0
moles). After stirring at room temperature for 2 hours, the mixture was
evaporated to dryness in air at 120°C and held at that temperature over
the weekend. The dried catalyst was ground to a powder with a mortar
and pestle and then calcined in air at 400°C for 24 hours.

PREPARATION EXAMPLE 5
Preparation of 90%Chromium/10%Cobalt Catalyst (washed; 400°C)

A solution of 720.27 g $Cr(NO_3)_3[9(H_2O)]$ (1.80 moles) and 58.21 g
$Co(NO_3)_2[6(H_2O)]$ (0.20 mole) was prepared in 2000 mL of deionized
water. The solution was treated dropwise with 955 mL of 7.4M aqueous
ammonia which raised the pH from about 2.1 to about 8.5. The slurry was
stirred at room temperature overnight. The following day, the pH was the
increased from 8.05 to 8.5 by addition of aqueous ammonia. The solid
was collected in two 3 L fritted funnels and each portion washed with
15-20 L of deionized water. The washed solid was then evaporated to
dryness in air at 120°C for 24 hours. The dried catalyst was then calcined
in air at 400°C for 24 hours.

PREPARATION EXAMPLE 6
Preparation of 90%Chromium/10%Cobalt Catalyst
(6.7 eq. of excess NH_4NO_3, 400°C)

A solution of 72.03 g $Cr(NO_3)_3[9(H_2O)]$ (0.18 mole) and 5.82 g
$Co(NO_3)_2[6(H_2O)]$ (0.020 mole) was prepared in 200 mL of deionized
water. The solution was brought to pH 8.5 treatment with 7.4M aqueous
ammonia. The slurry was stirred at room temperature for 24 hours. The
mixture was then treated with a solution of 96.05 g of NH_4NO_3 (1.2 moles)
dissolved in 200 mL of water. The slurry was stirred for one hour and then
dried at 120°C in air for about 90 hours. The dried solids was crushed to
a powder and then placed in covered dish and calcined at 400°C for
24 hours in air.

General Procedure for Fluorocarbon Product Analysis

The following general procedure is illustrative of the method used for analyzing the products of fluorocarbon reactions. Part of the total reactor effluent was sampled on-line for organic product analysis using a

5   gas chromatograph equipped with a mass selective detector (GC-MS). The gas chromatography was accomplished with a 20 ft. (6.1 m) long x 1/8 in. (0.32 cm) diameter tubing containing Krytox® perfluorinated polyether on an inert carbon support. The helium flow was 30 mL/min $(5.0 \times 10^{-7}$ m^3/s). Gas chromatographic conditions were 60°C for an initial

10   hold period of three minutes followed by temperature programming to 200°C at a rate of 6°C/minute.

The bulk of the reactor effluent containing organic products and also inorganic acids such as HCl and HF was treated with aqueous caustic prior to disposal.

15   All vapor reactions were conducted at a nominal pressure of one atmosphere.

Legend

113 is CCl_2FCClF_2 114a is CF_3CCl_2F

115 is CF_3CClF_2 123 is $CHCl_2CF_3$

20   124 is $CHClFCF_3$ 124a is CHF_2CClF_2

125 is CHF_2CF_3 133a is CH_2ClCF_3

CT is contact time

COMPARATIVE EXAMPLE 1

Chromium oxide (6.05g, 4 mL, 12-20 mesh, (1.68 to 0.84 mm)),

25   prepared as described in COMPARATIVE PREPARATION EXAMPLE 1 was placed in a 1/2" (1.27 cm) diameter Inconel™ nickel alloy reactor tube heated in a furnace. The catalyst was heated from 200°C to 400°C in a flow of nitrogen (50 cc/min, 8.3×10^{-7} m^3/s) over the course of about 25 minutes, and then the temperature was lowered to 300°C while

30   maintaining the nitrogen flow for an additional 80 minutes. The flow of nitrogen was reduced to 35 cc/min $(5.8 \times 10^{-7}$ m^3/s) and HF was then admitted to the reactor at a flow rate of 12 cc/min $(2.0 \times 10^{-7}$ m^3/s). After 35 minutes, the temperature was raised to 325°C. After 60 minutes it was raised to 350°C. After 60 minutes it was raised to 375°C. After

35   90 minutes it was raised to 400°C. After 30 minutes it was raised to 425°C. After 20 minutes, the flow of nitrogen was reduced to 15 cc/min $(2.5 \times 10^{-7}$ m^3/s) and the flow of HF was increased to 28 cc/min $(4.7 \times 10^{-7}$ m^3/s). After 20 minutes, the flow of nitrogen was reduced to 5 cc/min

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$(8.3 \times 10^{-8}$ m^3/s) and the flow of HF was increased to 36 cc/min $(6.0 \times 10^{-7}$ m^3/s). After 20 minutes, the flow of nitrogen was shut off and the flow of HF was increased to 40 cc/min $(6.7 \times 10^{-7}$ m^3/s), and this condition was maintained for 120 minutes. The reactor temperature was adjusted to

5 350°C and HF and HCFC-124 vapor were fed to the reactor in molar ratio of 2:1 at a contact time of 3.3 seconds. The GC-MS analysis of the reactor effluent is given below.

Component	Mole %
HFC-125	77.9
CFC-115	2400 ppm
HCFC-124	12.8
HCFC-124a	0.5
CFC-114a	0.2
HCFC-123	7.9
CFC-113	0.1

COMPARATIVE EXAMPLE 2

Cobalt-substituted chromium oxide (Cr/Co 90/10, 6.75g, 4 mL, 12-20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 5 was placed in a 1/2" (1.27 cm) diameter

20 Inconel™ nickel alloy reactor tube heated in a furnace. The catalyst was heated from 200°C to 400°C in a flow of nitrogen (50 cc/min, 8.3×10^{-7} m^3/s) over the course of about 25 minutes, and then the temperature was lowered to 300°C while maintaining the nitrogen flow for an additional 80 minutes. The flow of nitrogen was reduced to 35 cc/min $(5.8 \times 10^{-7}$ m^3/s)

25 and HF was then admitted to the reactor at a flow rate of 12 cc/min $(2.0 \times 10^{-7}$ m^3/s). After 35 minutes, the temperature was raised to 325°C. After 60 minutes it was raised to 350°C. After 60 minutes it was raised to 375°C. After 90 minutes it was raised to 400°C. After 30 minutes it was raised to 425°C. After 20 minutes, the flow of nitrogen was reduced to

30 15 cc/min $(2.5 \times 10^{-7}$ m^3/s) and the flow of HF was increased to 28 cc/min $(4.7 \times 10^{-7}$ m^3/s). After 20 minutes, the flow of nitrogen was reduced to 5 cc/min $(8.3 \times 10^{-8}$ m^3/s) and the flow of HF was increased to 36 cc/min $(6.0 \times 10^{-7}$ m^3/s). After 20 minutes, the flow of nitrogen was shut off and the flow of HF was increased to 40 cc/min $(6.7 \times 10^{-7}$ m^3/s), and this condition

35 was maintained for 120 minutes. The reactor temperature was adjusted to 350°C and HF and HCFC-124 vapor were fed to the reactor in molar ratio of 2:1 at a contact time of 3.3 seconds. The GC-MS analysis of the reactor effluent is given below.

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Component	Mole %
HFC-125	19.1
CFC-115	48 ppm
HCFC-124	77.5
HCFC-124a	0.4
HCFC-123	3.0

COMPARATIVE EXAMPLE 3

Cobalt-substituted chromium oxide (Cr/Co 90/10, 5.66g, 4 mL, 12-20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 6 was placed in a 1/2" (1.27 cm) diameter Inconel™ nickel alloy reactor tube heated in a furnace. The catalyst was heated from 200°C to 400°C in a flow of nitrogen (50 cc/min, 8.3×10^{-7} m^3/s) over the course of about 25 minutes, and then the temperature was lowered to 300°C while maintaining the nitrogen flow for an additional 80 minutes. The flow of nitrogen was reduced to 35 cc/min (5.8×10^{-7} m^3/s) and HF was then admitted to the reactor at a flow rate of 12 cc/min (2.0×10^{-7} m^3/s). After 35 minutes, the temperature was raised to 325°C. After 60 minutes it was raised to 350°C. After 60 minutes it was raised to 375°C. After 90 minutes it was raised to 400°C. After 30 minutes it was raised to 425°C. After 20 minutes, the flow of nitrogen was reduced to 15 cc/min (2.5×10^{-7} m^3/s) and the flow of HF was increased to 28 cc/min (4.7×10^{-7} m^3/s). After 20 minutes, the flow of nitrogen was reduced to 5 cc/min (8.3×10^{-8} m^3/s) and the flow of HF was increased to 36 cc/min (6.0×10^{-7} m^3/s). After 20 minutes, the flow of nitrogen was shut off and the flow of HF was increased to 40 cc/min (6.7×10^{-7} m^3/s), and this condition was maintained for 120 minutes. The reactor temperature was adjusted to 350°C and HF and HCFC-124 vapor were fed to the reactor in molar ratio of 2:1 at a contact time of 3.3 seconds. The GC-MS analysis of the reactor effluent is given below.

Component	Mole %
HFC-125	62.0
CFC-115	200 ppm
HCFC-124	23.3
HCFC-124a	0.2
HCFC-133a	0.3
FCFC-114a	0.1
HCFC-123	14.0
FCFC-113	0.1

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EXAMPLE 4

Cobalt-substituted chromium oxide (Cr/Co 99/1, 5.96g, 4 mL, 12-20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 2 was placed in a 1/2" (1.27 cm) diameter

5   Inconel™ nickel alloy reactor tube heated in a furnace. The catalyst was heated from 200°C to 400°C in a flow of nitrogen (50 cc/min, 8.3×10^{-7} m^3/s) over the course of about 25 minutes, and then the temperature was lowered to 300°C while maintaining the nitrogen flow for an additional 80 minutes. The flow of nitrogen was reduced to 35 cc/min (5.8×10^{-7} m^3/s)

10   and HF was then admitted to the reactor at a flow rate of 12 cc/min (2.0×10^{-7} m^3/s). After 35 minutes, the temperature was raised to 325°C. After 60 minutes it was raised to 350°C. After 60 minutes it was raised to 375°C. After 90 minutes it was raised to 400°C. After 30 minutes it was raised to 425°C. After 20 minutes, the flow of nitrogen was reduced to

15   15 cc/min (2.5×10^{-7} m^3/s) and the flow of HF was increased to 28 cc/min (4.7×10^{-7} m^3/s). After 20 minutes, the flow of nitrogen was reduced to 5 cc/min (8.3×10^{-8} m^3/s) and the flow of HF was increased to 36 cc/min (6.0×10^{-7} m^3/s). After 20 minutes, the flow of nitrogen was shut off and the flow of HF was increased to 40 cc/min (6.7×10^{-7} m^3/s), and this condition

20   was maintained for 120 minutes. The reactor temperature was adjusted to 350°C and HF and HCFC-124 vapor were fed to the reactor in molar ratio of 2:1 at a contact time of 3.3 seconds. The GC-MS analysis of the reactor effluent is given below.

Component	Mole %
25 HFC-125	76.2
CFC-115	1400 ppm
HCFC-124	13.5
HCFC-124a	0.2
HCFC-133a	0.4
30 CFC-114a	0.2
HCFC-123	9.2
CFC-113	0.1

EXAMPLE 5

Cobalt-substituted chromium oxide (Cr/Co 98/2, 5.77g, 4 mL,

35   12-20 mesh, (1.68 to 0.84 mm)), prepared as described in PREPARATION EXAMPLE 3 was placed in a 1/2" (1.27 cm) diameter Inconel™ nickel alloy reactor tube heated in a furnace. The catalyst was heated from 200°C to 400°C in a flow of nitrogen (50 cc/min, 8.3×10^{-7}

m³/s) over the course of about 25 minutes, and then the temperature was lowered to 300°C while maintaining the nitrogen flow for an additional 80 minutes. The flow of nitrogen was reduced to 35 cc/min (5.8×10^{-7} m³/s) and HF was then admitted to the reactor at a flow rate of 12 cc/min

5   (2.0×10^{-7} m³/s). After 35 minutes, the temperature was raised to 325°C. After 60 minutes it was raised to 350°C. After 60 minutes it was raised to 375°C. After 90 minutes it was raised to 400°C. After 30 minutes it was raised to 425°C. After 20 minutes, the flow of nitrogen was reduced to 15 cc/min (2.5×10^{-7} m³/s $\times 10^{-7}$ m³/s) and the flow of HF was increased to

10   28 cc/min (4.7×10^{-7} m³/s). After 20 minutes, the flow of nitrogen was reduced to 5 cc/min (8.3×10^{-8} m³/s) and the flow of HF was increased to 36 cc/min (6.0×10^{-7} m³/s). After 20 minutes, the flow of nitrogen was shut off and the flow of HF was increased to 40 cc/min (6.7×10^{-7} m³/s), and this condition was maintained for 120 minutes. The reactor temperature

15   was adjusted to 350°C and HF and HCFC-124 vapor were fed to the reactor in molar ratio of 2:1 at a contact time of 3.3 seconds. The GC-MS analysis of the reactor effluent is given below.

Component	Mole %
HFC-125	74.8
CFC-115	780 ppm
HCFC-124	14.9
HCFC-124a	0.2
HCFC-133a	0.3
CFC-114a	0.2
HCFC-123	9.5
CFC-113	0.1

EXAMPLE 6

Cobalt-substituted chromium oxide (Cr/Co 95/5, 5.95g, 4 mL, 12-20 mesh, (1.68 to 0.84 mm)), prepared as described in

30   PREPARATION EXAMPLE 4 was placed in a 1/2" (1.27 cm) diameter Inconel™ nickel alloy reactor tube heated in a furnace. The catalyst was heated from 200°C to 400°C in a flow of nitrogen (50 cc/min, 8.3×10^{-7} m³/s) over the course of about 25 minutes, and then the temperature was lowered to 300°C while maintaining the nitrogen flow for an additional

35   80 minutes. The flow of nitrogen was reduced to 35 cc/min (5.8×10^{-7} m³/s) and HF was then admitted to the reactor at a flow rate of 12 cc/min (2.0×10^{-7} m³/s). After 35 minutes, the temperature was raised to 325°C. After 60 minutes it was raised to 350°C. After 60 minutes it was raised to

375°C. After 90 minutes it was raised to 400°C. After 30 minutes it was raised to 425°C. After 20 minutes, the flow of nitrogen was reduced to 15 cc/min (2.5×10^{-7} m^3/s) and the flow of HF was increased to 28 cc/min (4.7×10^{-7} m^3/s). After 20 minutes, the flow of nitrogen was reduced to

5   5 cc/min and the flow of HF was increased to 36 cc/min (6.0×10^{-7} m^3/s). After 20 minutes, the flow of nitrogen was shut off and the flow of HF was increased to 40 cc/min (6.7×10^{-7} m^3/s), and this condition was maintained for 120 minutes. The reactor temperature was adjusted to 350°C and HF and HCFC-124 vapor were fed to the reactor in molar ratio of 2:1 at a

10 contact time of 3.3 seconds. The GC-MS analysis of the reactor effluent is given below.

Component	Mole %
HFC-125	71.4
CFC-115	440 ppm
HCFC-124	16.4
HCFC-124a	0.2
HCFC-133a	0.3
FCFC-114a	0.2
HCFC-123	11.3

15

EXAMPLES 7-9

20

Additional examples of the conversion of HCFC-124 to HFC-125 are summarized in Table 2 along with the corresponding data for EXAMPLES 1-6. In Table 2, the ppm of 115 is the ppm of 115 relative only to the amount of 125 produced (moles of 115/moles of 125 *

25 1000000).

Table 2. Product Distribution at 350°C, 3.3 sec CT,

and an HF/124 Ratio of 2.0

Ex.	% Co	% 125	ppm 115	% 124	% 124a	% 133a	% 114a	% 123	% 113
C1	0	77.9	2400	12.8	0.5	0	0.2	7.9	0.1
C2	10[b]	19.1	48	77.5	0.4			3.0	
C3	10[b] excess NH_4NO_3	62.0	200	23.3	0.2	0.3	0.1	14.0	0.1
4	1	76.2	1400	13.5	0.2	0.4	0.2	9.2	0.1
5	2	74.8	780	14.9	0.2	0.3	0.2	9.5	0.1
6	5 excess NH_4NO_3	71.4	440	16.4	0.2	0.3	0.2	11.3	0.1
7	2	77.6	1600	12.8	0.2	0.4	0.2	8.6	0.1
8	3	64.8	n.d.[a]	22.5	0.2	0.1	0.1	12.2	0.1
9	5	65.8	320	21.5	0.2	0.2	0.1	12.0	0.1

a.   n.d. means not detected by GC-MS.

b. As suggested in U.S. Patent Application 60/405,220 [CL2099 US PRV] filed August 22, 2002, these catalysts may be expected to differ significantly from compositions containing lower proportions of Co due to the solubility limit of Co in alpha chromium oxide.

COMPARATIVE EXAMPLES 10, 17 AND 18 AND EXAMPLES 11-16

In the examples given in Table 3, the reactor temperature was gradually increased from 300°C to 370°C while maintaining a contact time of 3.3 seconds and a molar ratio of HF to $CHClFCF_3$ of 2.0. The activity of the various Co-substituted α-Cr_2O_3 catalysts is compared by determining the temperature where the product contained 70% HFC-125 and the selectivity is compared by determining the amount of CFC-115 in the product at the temperature where the product is 70% HFC-125. The concentration of CFC-115 and the %125 was monitored at 330°C, well below equilibrium conditions. The catalysts used are from the EXAMPLES 1-9 as noted.

Table 3. Activity and Selectivity at 3.3 sec CT, and an HF/124 Ratio of 2.0

Example	Catalyst from Example.	% Co	ppm 115 @ 70% 125	Temp °C @ 70% 125	%125 @ 330 C
C10	C1	0	1000	335	66
11	4	1	420	335	67
12	5	2	210	330	70
13	7	2	550	337	62
14	8	3	830	363	48
15	9	5	1000	358	55
16	6	5 excess NH_4NO_3	447	347	59
C17[a]	C2	10	Not active enough[b]	Not active enough[b]	13
C18[a]	C3	10 excess NH_4NO_3	Not active enough[b]	Not active enough[b]	48

a. As suggested U.S. Patent Application 60/405,220 [CL2099 US PRV] filed August 22,
2002, these catalysts may be expected to differ significantly from compositions containing
lower proportions of Co due to the solubility limit of Co in alpha chromium oxide.
b. 70% HFC-125 not achieved in this example.

EXAMPLE 19

Cobalt-substituted chromium oxide (Cr/Co 95/5, 29.04g, 20 mL,
-12 to +20 mesh, (1.68 to 0.84 mm)), prepared as described in
PREPARATION EXAMPLE 4 was placed in a 5/8" (1.58 cm) diameter
Inconel™ nickel alloy reactor tube heated in a fluidized sand bath. The
catalyst was heated from 77°C to 175°C in a flow of nitrogen (25 cc/min,
4.2×10^{-7} m^3/s) over the course of about 1.2 hours. HF and nitrogen were
then co-fed to the reactor at a flow rate of 50 cc/min (8.3×10^{-7} m^3/s) each.
After 1.5 hours, the nitrogen flow was decreased to 20 cc/min (3.3×10^{-7}
m^3/s) and the HF flow increased to 80 cc/min (1.3×10^{-6} m^3/s). The
reactor temperature was gradually increased to 413°C during a 5 hour
period and maintained at 413°C for an additional 0.6 hour. At the end of
this period, the HF flow was stopped and the reactor cooled to 300°C
under nitrogen flow (20 sccm, 3.3×10^{-7} m^3/s).

The catalyst prepared as above was placed in the reactor, purged
with nitrogen and HF at 300°C. HF and HCFC-123 vapor were co-fed to
the reactor in molar ratio of 6:1 at a contact time of 30 seconds. The GC-
MS analysis of the reactor effluent is given below.

19

Component	Mole %
HFC-125	26.7
HCFC-124	49.2
HCFC-124a	0.2
CFC-114a	1.4
HCFC-123	22.1
CFC-115	0.16

5

Other products included CFC-113a and CFC-113.

<u>CLAIMS</u>

What is claimed is:

1. A process for the preparation of pentafluoroethane, comprising:

    (a) contacting a mixture comprising hydrogen fluoride and at least one one starting material selected from haloethanes of the formula CX_3CHX_2 and haloethenes of the formula $CX_2=CX_2$, where each X is independently selected from the group consisting of F and Cl provided that no more than four of X are F, with a fluorination catalyst in a reaction zone to produce a product mixture comprising HF, HCl, pentafluoroethane, underfluorinated halogenated hydrocarbon intermediates and less than 0.2 mole percent chloropentafluoroethane based on the total moles of halogenated hydrocarbons in the product mixture;

wherein said fluorination catalyst comprises at least one chromium-containing component selected from (i) a crystalline cobalt-substituted alpha-chromium oxide where from about 0.05 atom % to about 6 atom % of the chromium atoms in the alpha-chromium oxide lattice are replaced by trivalent cobalt, and (ii) a fluorinated crystalline oxide of (i).

2. The process of Claim 1 further comprising

    (b) separating the product of step (a) to recover CF_3CHF_2 as a product and to obtain underfluorinated halogenated hydrocarbon intermediates; and

    (c) returning underfluorinated halogenated hydrocarbon intermediates obtained in step (b) back to the step (a) reaction zone;

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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   C07C17/20   C07C17/21   C07C19/08   B01J23/86

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   C07C   B01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	EP 1 038 858 A (DAIKIN IND LTD) 27 September 2000 (2000-09-27) page 9, line 45; claims 1,2,10; example 3	1,2
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| [X] | Further documents are listed in the continuation of box C. | [X] | Patent family members are listed in annex. |

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Date of the actual completion of the international search	Date of mailing of the international search report
4 December 2003	22/12/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Bonnevalle, E

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INTERNATIONAL SEARCH REPORT

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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